



Multicriteria selection for an alumina-cement plant location in East Azerbaijan province of Iran

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Synopsis

One of the most important factors leading to the success of a cement plant is its location. A multicriteria decision-making method is used to rank alternative plant locations. The set of criteria is established and corresponding criteria should be established for each case study, although this multicriteria decision-making approach has broader applicability. In this paper, the analytic hierarchy process (AHP) with 5 criteria is used to develop a location evaluation hierarchy for an alumina-cement plant in East Azerbaijan province of Iran. Five alternatives for the plant location are evaluated. The main criteria are transportation, water supply, power supply, fuel supply and land. Other criteria have the same importance as these five alternatives. The alternatives are ranked by a multicriteria method and the best site is proposed.

Keywords: plant location; multicriteria decision-making

Introduction

Aluminium is light, strong and 100 per cent recyclable. Aluminium does not create pollution and is the most environmentally friendly metal available; moreover, it can easily be combined with all other metals. The result is usually the lightest and strongest possible of alloys. Aluminium is therefore used in airplane manufacturing, shipbuilding, railroad, and automobile industries because of its features, which usually reduce vehicle weight, lower fuel usage and increase speed. According to the rapid growth of consumption of aluminium, which has been called the metal of the century, this product is known as a strategic product.

At present the aluminum industry of Iran (the aluminium smelter IRALCO) uses imported aluminium as raw material. Iran has large proven deposits of aluminium ores (alunite, bauxite, and nepheline), which may be used as the domestic raw material resource for development of the aluminum industry. So, the Iranian aluminum industry has many potential projects for its development and there will be a complete makeover within the industry during the fourth and fifth development plans.

One of these projects is for the production of alumina from Azerbaijan's nepheline, with a capacity of 200 000 tons. The main objectives of the alumina production project include: annual production of 200 000 tons of alumina as raw material for producing aluminium, annual foreign exchange savings, using bauxite from domestic sources for alumina production, reducing dependence on alumina imports, and transfer of technical know-how for producing alumina in the country.

Production of 200 000 tons of alumina from nepheline syenite ore is counted as a national project and is allotted a huge investment. So it should have a very precise inspection for site location. In addition, plant location is an important factor leading to the success of plant management since it will determine the convenience of service to customers and how many are attracted. In addition, location also exerts a significant effect on market share and the profit-making ability of the plant. This paper has, therefore, applied multiple criteria decision making (MCDM) method to evaluate plant location alternatives, determining the importance (weight) of each evaluation criterion.

Market study

Owing to the direct connection between the consumption of alumina and aluminium, the study of the supply and demand of alumina is based on the future plans for the alumina in the country. At the moment, the nominal capacity of the Iran aluminum smelter (IRALCO) is 200 000 tons per year and a unit of 330 000 tons of aluminium (Almahdi) is going to be established in Bandar Abbas, which will increase the total capacity of the

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country's smelter to 530 000 tons. Since, alumina consumption for 1 ton of aluminium is 2 tons, the need for this product will be about 1,060,000 tons per year and even Jajarm project is implemented (bauxite, tube digestion process) the need for other alumina plants will still exist.

In addition, in this project there is another product (cement) for which, at the moment, Iran's nominal capacity is about 30 million tons per year and it seems it will need 50 millions tons per year in the year 2020. So establishing the alumina-cement project from nepheline ore, would reduce some of Iran's needs and the government will support this project.

Plant capacity

Alumina-cement plant products are alumina, cement, sodium carbonate and potash. Annual production of each product is given in Table I.

Raw material resource

With the above capacities of the alumina-cement plant, required raw Materials are (Vami, 1992):

- 1.28 million tons of nepheline ore per year, which is extracted from the Razgah deposit whose reserves of quality ore are estimated at about 100.9 million tons.
- 3.62 million tons of limestone ore per year, which is extracted from the Areshtenab and Esmaeilabad deposits, whose reserves are estimated at 65 and 183 million tons, respectively.
- 143 000 tons of bauxite ore per year
- 68 000 tons of iron ore per year
- 170 000 tons of gypsum per year.

With the above capacity of the alumina plant, the explored reserves of nepheline ores would secure its operation for 90 years and explored reserves of limestone (a second major raw material) for 24 year. The location of Razgah, Areshtenab and Esmaeilabad mines are shown in Figure1.

Criteria and alternatives for plant site selection

The geographical location of the final plant can have a strong influence on the success of an industrial venture.

Considerable care must be exercised in selecting the plant site and many different factors must be considered. Selecting the optimum plant site location is an iterative process that requires the reduction of various considerations. The most important factors are:

- Geographic considerations such as topographic and plan metric maps
- Technical considerations such as geologic maps, ground stability, mine(s) location(s), water sources, utility sources, transportation systems and capabilities, climate data, plant specifications and refuse disposal requirements
- Business considerations such as competitive environment, royalties, tax laws, materials availability, contractor availability, labour pool, housing availability and medical care availability
- Legal considerations such as property ownership, surface rights, regulatory requirements, statutory requirements and contractual requirements
- Political considerations such as development incentives, environmental limitations (air, water, noise, subsidence and aesthetics), employment rates and business posture.

Table I

Annual production of each product of the alumina-cement plant

Product	Unit	Annual production
Alumina	tons	200 000
Cement	tons	3 400 000
Sodium carbonate	tons	35 400
Potash	tons	115 100
Potassium sulphate	tons	2 600

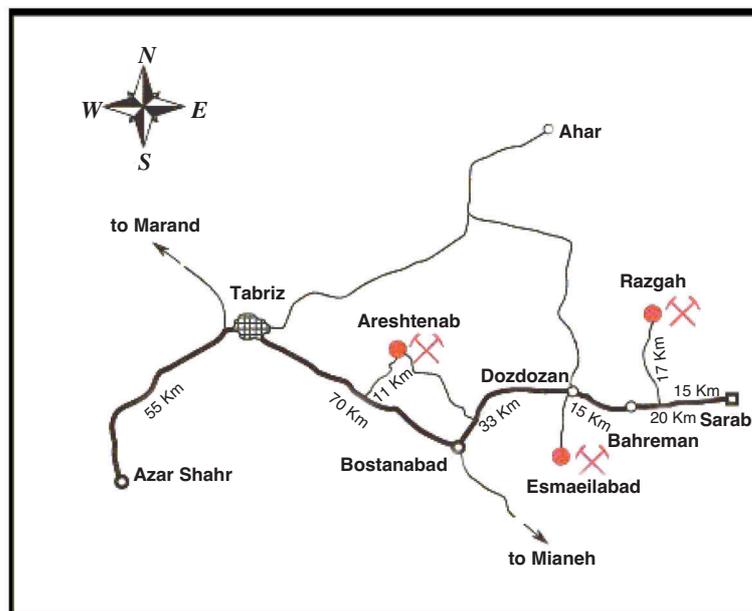


Figure 1—Location of Razgah, Areshtenab and Esmaeilabad mines

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Once the lowest-cost location has been identified, then the incremental cost of alternative locations that are desirable for various technical, business, or political reasons can be determined. One starts this process by assembling all of the known information concerning the project and general plant location.

In this study, the following criteria are considered for determining suitable location for the plant:

- Transportation
- Water supply
- Power supply
- Fuel supply
- Land.

Other criteria are also important for each alternative. Based upon the criteria, 5 alternatives for the plant location are considered. Figure 2 shows the location of these alternatives.

Transportation consideration

The source of raw materials is one of the most important factors influencing the selection of a plant site. As a general rule, it is most economical to have the plant located as close to the mine(s) as possible. This is especially true when run-of-mine material requires a high degree of concentration as transportation costs are normally reduced then. Table II shows the transport conditions in an alumina-cement plant project.

Water supply

The alumina-cement plant uses large quantities of water as a raw material (5 million cubic metres per year). The plant therefore must be located where a dependable supply of water is available. For 287 working days per year and 3 shifts per day, the plant will require 200 litres of water per second. In this region, litres 8 wells are required. Based up on the aquifer in this region, 5 wells must be drilled in Sharabyan and 3 wells must be drilled in Ojanchi. Water will be transported by pipe. Table III shows the average distance of each site from the Sharabyan plain and Ojanchi.

Power supply

The estimated electrical supply requirement will be 800 megawatts hour (Mwh), which can be provided by the electricity national network. The electrical supply requirement will be provided from the 230 Kilo volt (KV) Tekmehdash electricity post. The distance of each site from the Tekmehdash electricity post is shown in Table IV.

Fuel supply

The estimated fuel supply requirement will be 700 million cubic metres of gas per year, which can be provided by a national gas line. The distance of each site from the national gas line is shown in Table V.

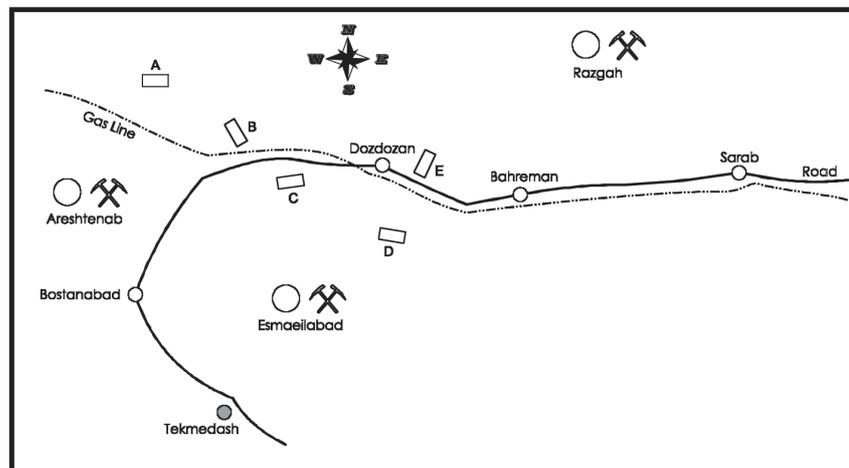


Figure 2—Location of alternatives

	Unit	A	B	C	D	E
Site distance from Razghah mine	km	41	35	27	28	17
Annual production of Razghah mine	million ton	1.28	1.28	1.28	1.28	1.28
Distance-production	km.million ton	52.48	44.8	34.56	35.84	21.76
Site distance from Areshtenab mine	km	11	15	22	27	35
Annual production of Areshtenab mine	million ton	2.38	2.38	2.38	2.38	2.38
Distance-production	km.million ton	26.18	35.7	52.36	64.26	83.3
Site distance from Esmailabad mine	km	24	16	12	9	17
Annual production of Esmailabad mine	million ton	1.24	1.24	1.24	1.24	1.24
Distance-production	km.million ton	29.76	19.84	14.88	11.16	21.08
Total	km.million ton	108.42	100.34	101.8	111.26	126.14

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Table III
Average distance of each site from Sharabyan plain and Ojanchi

	Unit	A	B	C	D	E
Distance from Sharabyan	km	25	15	3	5	6
Distance from Ojanchi	km	7	10	16	25	25

Table IV
Distance of each site from Tekmedash electricity post

	A	B	C	D	E
Distance from Tekmedash electricity post (km)	34	28	24	25	34

Table V
Distance of each site from gas line

	A	B	C	D	E
Distance from gas line (m)	2500	250	2000	4000	2000

Land consideration

To build this plant, 400 hectares land are required. Site A and site E are suitable for agriculture activities but site B, site C and site D are not.

Plant site selection using AHP technique

The AHP is a systematic procedure for representing the elements of a problem, hierarchically. The AHP method was developed by Saaty (Saaty, 1990; Saaty, 1982). It can enable decision makers to represent the interaction of multiple factors in complex, unstructured situations. The procedure is based on the pairwise comparison of decision elements with respect to attributes or alternatives. A pairwise comparison matrix $n \times n$ is formed, where n is the number of elements to be compared. The procedures used in this paper may be summarized as follows:

Structuring the hierarchy for evaluation

The AHP method is used to make the decomposition (or structuring) of the problem as a hierarchy. In general, the AHP method divides the problem into three levels (Saaty T.L., 1991):

- Define a goal for resolving the problem
- Define objectives for achieving the goal
- Determine evaluation criteria for each objective.

Figure 3 depicts the hierarchy structure of the alumina-cement plant location. The first level represents the overall objective, the second level consists of attributes and at the third level there are five alternatives that need to be ranked.

Constructing the pairwise comparison matrix

After structuring a hierarchy, the pairwise comparison matrix for each level is constructed. During the pairwise comparison, a nominal scale is used for the evaluation. The scale used in AHP for preparing the pairwise comparison matrix is a discrete scale from 1 to 9, as presented in Table VI. In the evaluation process (by experts), the AHP questionnaire sheet for restaurant location is used. The sheet for the objective level is presented in Table VII; it is used in comparing objectives, one on the left with one on the right.

Calculating the weights and testing the consistency for each level

This step is to find the relative priorities of criteria or alternatives implied by these comparisons. The relative priorities are worked out using the theory of eigenvector. For example, if the pairwise comparison matrix is A , then $(A - \lambda_{\max} I) \cdot w = 0$

To calculate the eigenvalue λ_{\max} and the eigenvector $w = (w_1, w_2, \dots, w_n)$ weights can be estimated as relative priorities of criteria or alternatives.

Table VIII presents a pairwise comparison of the attributes. It is found from the comparison (Table VIII and Figure 4) that transportation is the most important (priority = 0.5999) and it is followed by power supply (priority = 0.1871). Again, the comparison of each alternative based on a particular factor is placed in the matrix. So five matrices are formed. Since the number of alternatives is five, the order of the matrix is 5×5 . Table IX to Table XIII present pairwise

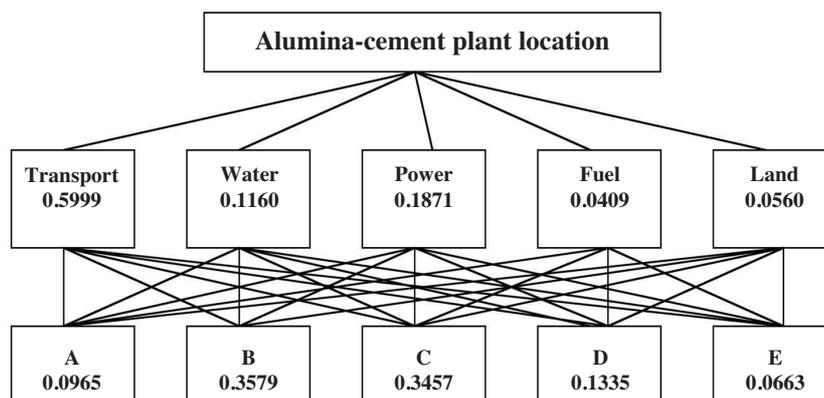


Figure 3—Hierarchy structure for alumina-cement plant location

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Table VI

Scale of relative importance (Saaty 1991)

Intensity of importance	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong
9	Extreme importance
2, 4, 6, 8	For compromise between the above values

Table VII

AHP questionnaire sheet for plant location

Objective	Absolute importance			Strong importance			Equal importance			Strong importance			Absolute importance			Objective
Transport	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	Water
Transport	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	Power
Transport	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	Fuel
Transport	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	Land
Water	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	Power
Water	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	Fuel
Water	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	Land
Power	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	Fuel
Power	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	Land
Fuel	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	Land

Table VIII

Pairwise comparison matrix of attributes

	Transport	Water	Power	Fuel	Land	Priority
Transport	1	6	5	9	9	0.5999
Water	1/6	1	1/2	3	1/3	0.1160
Power	1/5	2	1	5	4	0.1871
Fuel	1/9	1/3	1/5	1	1/2	0.0409
Land	1/9	1/3	1/4	2	1	0.0560

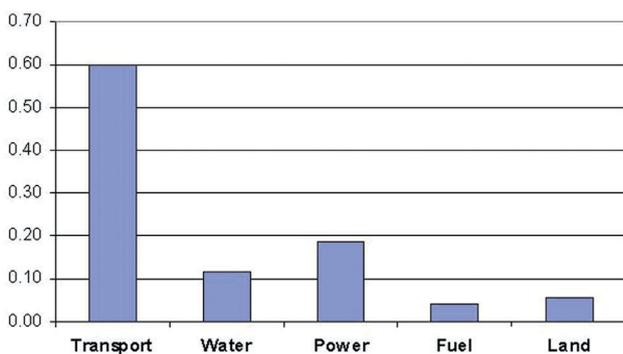


Figure 4—Comparison of attributes

Table IX

Comparison of transportation considerations

	A	B	C	D	E	Priority
A	1	1/5	1/4	1	4	0.0962
B	5	1	2	6	9	0.4722
C	4	1/2	1	4	8	0.3051
D	1	1/6	1/4	1	4	0.0931
E	1/4	1/9	1/8	1/4	1	0.0334

comparisons of the sites according to each of the attributes. The priorities of the sites against each attribute are presented in graphical form in Figure 5 to Figure 9. From the Tables and the corresponding Figures can be seen that when judged by the attributes of THE transportation consideration, water supply, power supply, fuel supply and land consideration, the most appropriate sites are, respectively, B, C, C, B, and A (or D).

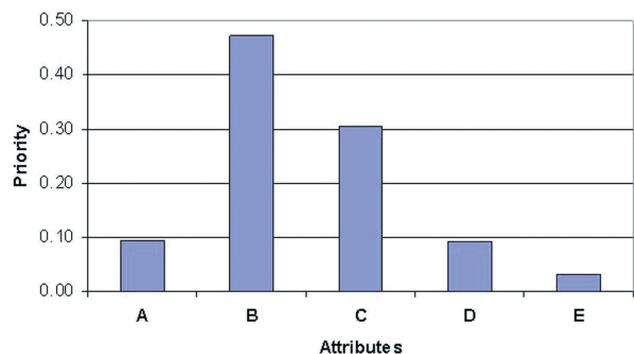


Figure 5—Comparison of sites with reference to transportation consideration

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Table X
Comparison of water supply

	A	B	C	D	E	Priority
A	1	1/5	1/9	1/4	1/3	0.0375
B	5	1	1/5	2	2	0.1695
C	9	5	1	6	7	0.5921
D	4	1/2	1/6	1	2	0.1191
E	3	1/2	1/7	1/2	1	0.0818

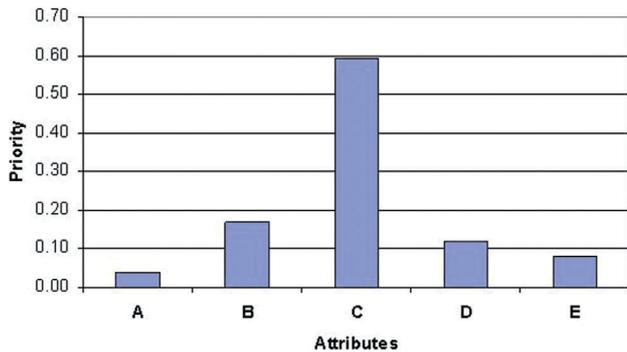


Figure 6—Comparison of sites with reference to water supply

Table XI
Comparison of power supply

	A	B	C	D	E	Priority
A	1	1/6	1/9	1/9	1	0.0354
B	6	1	1/4	1/3	6	0.1549
C	9	4	1	2	9	0.4552
D	9	3	1/2	1	6	0.3192
E	1	1/6	1/9	1/9	1	0.0354

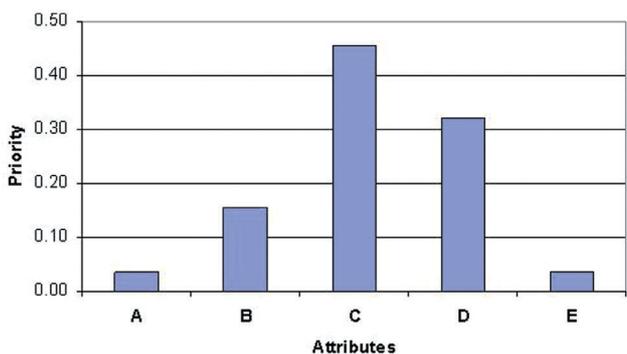


Figure 7—Comparison of sites with reference to power supply

Table XII
Comparison of fuel supply

	A	B	C	D	E	Priority
A	1	1/6	1/2	4	1/2	0.0928
B	6	1	5	9	5	0.5711
C	2	1/5	1	5	1	0.1504
D	1/4	1/9	1/5	1	1/5	0.0353
E	2	1/5	1	5	1	0.1504

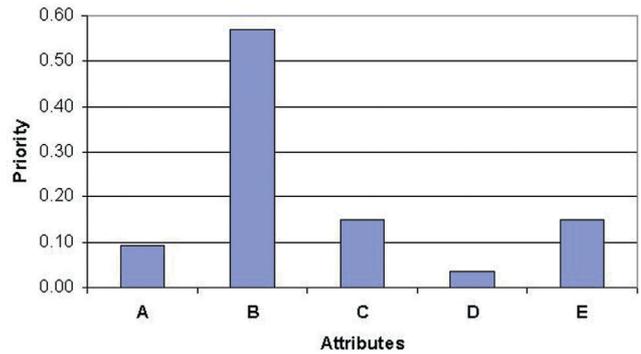


Figure 8—Comparison of sites with reference to fuel supply

Table XIII
Comparison of land consideration

	A	B	C	D	E	Priority
A	1	9	9	9	1	0.4286
B	1/9	1	1	1	1/9	0.0476
C	1/9	1	1	1	1/9	0.0476
D	1/9	1	1	1	1/9	0.0476
E	1	9	9	9	1	0.4286

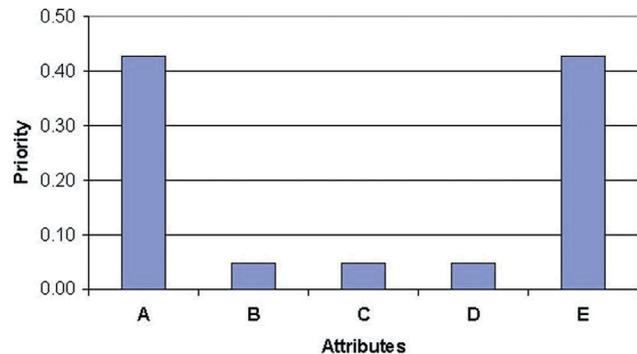


Figure 9—Comparison of sites with reference to land consideration

The overall rating of each site is computed by adding the product of the relative priority of each criterion and the relative priority of the site considering the corresponding criteria, e.g.

$$\text{Overall rating of site A} = (0.5999 \times 0.0962) + (0.1160 \times 0.0375) + (0.1871 \times 0.0354) + (0.0409 \times 0.0928) + (0.0560 \times 0.4286) = 0.0962$$

Table XIV gives the overall rating of each site. Figure 10 presents the composite ranking of the sites in graphical form. It is seen from Table XIV and Figure 9 that site B (with a rating of 0.3579) is most preferred and is followed by site C, D, A and E.

Calculation consistency index

Since the comparison is based on a subjective evaluation, a consistency ratio is required to ensure accuracy. The consistency index (*CI*) of the above-mentioned matrix is computed as follow:

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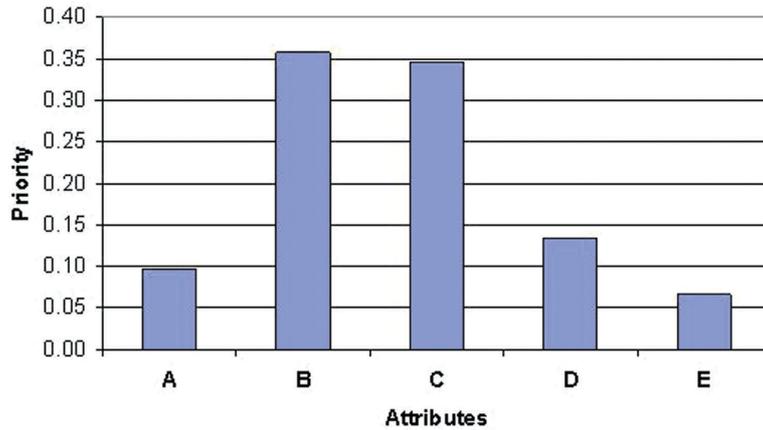


Figure 10—Overall rating

$$CI = \frac{\lambda_{\max} - n}{n - 1}$$

where λ_{\max} is the maximum or principal eigenvalue and n is the size of the matrix. The random consistency index (RI) is given by

$$RI = 1.98 \frac{n - 2}{n}$$

The consistency ratio (CR) is given by

$$CR = \frac{CI}{RI}$$

In the consistency test, the consistency index (CI) is utilized to determine the degree of consistency, generally speaking, when $CI < 0.1$ it is considered to be acceptable.

λ_{\max} , the consistency index, random consistency index and consistency ratio of the corresponding matrices are shown in Table XV.

Table XIV
Overall result/ final matrix

Factors	Priority	A	B	C	D	E
Transport	0.5999	0.0962	0.4722	0.3051	0.0931	0.0334
Water	0.1160	0.0375	0.1695	0.5921	0.1191	0.0818
Power	0.1871	0.0354	0.1549	0.4552	0.3192	0.0354
Fuel	0.0409	0.0928	0.5711	0.1504	0.0353	0.1504
Land	0.0560	0.4286	0.0476	0.0476	0.0476	0.4286
Overall		0.0965	0.3579	0.3457	0.1335	0.0663

Table XV
 λ_{\max} the consistency index, random consistency index and consistency ratio for different matrices

	Goal	Transport	Water	Power	Fuel	Land
Weight	1	0.5999	0.116	0.1871	0.0409	0.056
λ_{\max}	5.1311	5.1754	5.1625	5.1651	5	5.1741
CI	0.0435	0.0328	0.0438	0.0406	0.0413	0
RI	1.188	1.188	1.188	1.188	1.188	1.188
CR	0.0389	0.0293	0.0391	0.0363	0.0368	0

$$C.R. = \frac{C.I.}{R.I.} = \frac{0.0413 \times 0.0409 + 0.056}{1.121 + 1.188 \times 0.5999 + 1.188 \times 0.116 + 1.188 \times 0.1871 + 1.188 \times 0.0509 + 1.188 \times 0.056} = 0.0326 < 0.1$$

It is found for all the matrices, the consistency index and consistency ratio are less than 10 per cent. This indicates that decision makers are exhibiting coherent judgement in specifying the pairwise comparison of the criteria or alternatives.

Conclusion

Plant location involves the interaction of several subjective factors or criteria. Decisions are often complicated and many even embody contradiction. In this study, it was found that the transportation consideration was the most important factor (priority = 0.5999) for the selection of the alumina-cement plant location, followed by power supply (priority = 0.1871). From five alternative locations studied, location B was the most appropriate on consideration of all five factors in the plant location process. Unlike the traditional approach to plant location selection, AHP makes it possible to select the best location in a more scientific manner that preserves integrity and objectivity. The model is transparent and easy to comprehend and apply by the decision maker. For selecting a plant location, the AHP model is unique in its identification of multiple attributes, minimal data requirement and minimal time consumption.

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